A Compact Slot and Notch Loaded Microstrip Antenna for Wireless Applications

Ramesh Kumar Verma and Akhilesh Kumar

Abstract In this article, a compact modified wideband microstrip antenna (MSA) has been designed by cutting slots inside the patch and notches at the upper edge of the patch which provides a wide range of frequency band of 1259 MHz between frequency 1.653 GHz and 2.912 GHz. The proposed antenna design provides a wide bandwidth about 56.73% with −27.63 dB return loss resonating at 2.025 GHz frequency. It has 4.86 dB high gain and antenna efficiency of 95.77% at frequency 2.025 GHz. The antenna is designed with glass epoxy (FR-4) substrate and simulated by IE3D software. The antenna is excited via 50 Ω microstrip line feed. The resonating frequency band can be used for different applications in wireless communication.

Keywords Compact · Modified · Bandwidth · Wireless · FR-4 · IE3D · Microstrip line feed

1 Introduction

The advancement in wireless communication system has increased the interest of low profile as well as compact antennas with high gain and wideband working frequency bandwidth. The microstrip antennas have many advantages such as light weight, low profile, and compactness but the major disadvantages of MSA are its narrow bandwidth, low efficiency, spurious feed radiation, and smaller gain. There are numerous substrate materials whose dielectric constant that lies between 2.2 and 12 can be utilized for designing of an antenna [1]. The substrate having lower dielectric constant provides good efficiency and large bandwidth. The bandwidth of microstrip antenna

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can be raised by using various strategies, for example, taking different shapes of antenna patch and loading antenna patch with various kinds of notches and slots [2].

Neyestanak et al. [3] presented a W-shape antenna having 36.7% (800 MHz) bandwidth with large size of 70 × 50 mm. Ansari et al. [4] designed a disk shape single as well as multi-layer antenna of size 88 × 62 mm resonating at 3 GHz with fractional bandwidth 36.5% (985 MHz) for WLAN and WiMAX application. Verma and Srivastava [5] designed an H-shape patch antenna of size 39.04 × 47.64 mm showing bandwidth of 35.61% (710 MHz) loaded with three square slots. Wu and Wong [6] proposed direct coupled antenna of size 52.87 × 40 mm resonating at 2.879 GHz with 12.7% (365 MHz) bandwidth. Kamakshi et al. [7] designed an antenna with large size of 120 × 80 mm having three notches and one slot resonating at 1.84 GHz. Rajpoot et al. [8] designed an antenna of I-shape patch with overall size of 40.06 × 48.72 mm resonating at 2.41 GHz with 45.72% (970 MHz) bandwidth. Verma and Srivastava [9] proposed an antenna with inverted T-shape slot of size 38.43 × 46.86 mm having bandwidth of 48.25% (1179 MHz). Zhang et al. [10] designed an antenna of size 88 × 88 mm resonating at 2.45 GHz with bandwidth of 24.8% (650 MHz). Bala et al. [11] presented a metamaterial-based antenna of size 40 × 48 mm with 41% (1118 MHz) bandwidth resonating at 2.73 GHz. Sze and Wong [12] proposed an antenna of size 60 × 50 mm with two slots of right angle shape and a U-shape slot with narrow bandwidth of 53 MHz bandwidth. Mishra et al. [13, 14] designed a slot loaded for both dual and wideband stacked antenna and petal shape dual band gap coupled antenna. Verma and Srivastava [15] presented an inverted Y-shape patch antenna of size 33 × 40 mm with fractional bandwidth of 36.30% (933 MHz). Singh et al. [16] presented a circular patch antenna of hexa-band characteristics with inverted L-shape notch. Gupta et al. [17] presented a wideband gap and direct coupled antenna resonating at 2.399 GHz.

In this paper, bandwidth of MSA of compact size 38.42 × 46.86 mm (ground) has been enhanced by cutting three notches (6 × 6 mm, 6 × 6 mm, and 24 × 8 mm) and three slots (5 × 5 mm, 5 × 5 mm, and 15 × 5 mm) in antenna patch which is excited by microstrip line feed of 50 Ω. The designed antenna operated at 2.025 GHz frequency with 56.73% (1259 MHz) bandwidth between frequency 1.653 GHz and 2.912 GHz which is appropriate for WLAN and WiMAX.

2 Antenna Design

For designing of rectangular shape patch antenna, width and length of patch are calculated by using Eqs. (1)–(6) as given below [18].

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where c is speed of light (3×10^8 m/s) in air, f_r is design frequency, and ε_r is dielectric constant of material.

Effective dielectric constant $\varepsilon_{\text{reff}}$ is given as [18]

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12\text{h}}{\text{W}}\right)^{-\frac{1}{2}} \quad (2)$$

ΔL (extension length) of patch is calculated by [18]

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

Actual length (L) can be calculated by utilizing the value of (ΔL) as [18]

$$L = \frac{c}{2f_{r_{\sqrt{\varepsilon_{\text{reff}}}}}} - 2\Delta L \quad (4)$$

Ground layer length and width of can be calculated as [18]

$$L_{\text{g}} = L + 6h \quad (5)$$

$$W_g = W + 6h \quad (6)$$

3 Design Specifications of Antenna

The antenna specifications that are essentially required for designing of antenna are illustrated in Table 1. FR-4 substrate that has dielectric constant of 4.4 is used for proposed antenna design. The proposed antenna is designed for design frequency 2.45 GHz. The altitude of dielectric substrate (h) is 1.6 mm, and its loss tangent (tan δ) is 0.02. Microstrip line feed of 50 Ω is utilized for the excitation of radiating patch.

Table 1 Antenna design specifications

S. No	Parameter	Value	S. No	Parameter	Value (mm)
1	Dielectric constant ε_r	4.4	5	Patch length (Lp)	28.82
2	Design frequency (f_r)	2.45 GHz	6	Patch width (Wp)	37.26
3	Substrate height (h)	1.6 mm	7	Ground length (Lg)	38.42
4	Speed of light (c)	3×10^8 m/s	8	Ground width (Wg)	46.86

4 Method of Antenna Design

By using above equations and specification given in Table 1, the dimensions of the antenna geometry are calculated at 2.45 GHz frequency. The size of patch has been calculated which are 28.82 mm (length) and 37.26 mm (width), respectively. The size of ground plane is calculated by simply adding 6 h (9.6 mm) in both length (Lp) and width (Wp) of patch. The length and width of ground are considered as 38.42 mm and 46.86 mm, respectively. In designing of proposed antenna geometry, initially a rectangular ground was formed with calculated size and a patch at 1.6 mm above ground. The ground and patch loaded antenna geometry is shown in Fig. 1a. The patch of antenna was modified by slots and notches of appropriate dimension for performance improvement.

The proposed antenna is designed by loading a pair of square notches of size 6 × 6 mm at top corner of patch and slots of different sizes in conventional patch antenna. A vertical notch of dimension 24 × 8 mm is inserted at top middle of patch along with two square slots of size 5 × 5 mm which is y-axis symmetrically on both side of rectangular patch and a horizontal rectangular slot of size 15 × 5 mm at bottom side of patch. The structure of proposed slotted antenna is illustrated in Fig. 1b. The dimensional specifications of slots and notches are shown in Table 2. After the

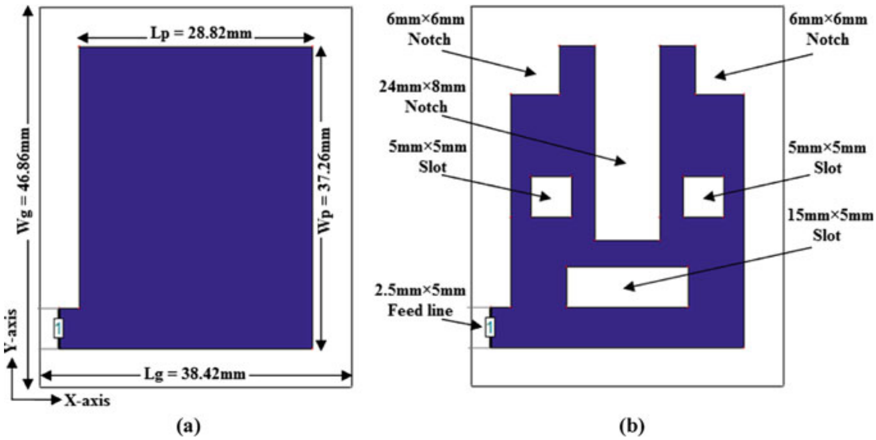


Fig. 1 Design of **a** Ground and patch loaded antenna **b** Notch and slot loaded geometry (proposed)

Table 2 Slot and notch specifications

S. No	Parameter	Value	S. No	Parameter	Value
1	Square notches	6 × 6 mm	4	Horizontal slot	15 × 5 mm
2	Square slots	5 × 5 mm	5	Feed length	2.5 mm
3	Vertical notch	24 × 8 mm	6	Feed width	5 mm

designing of ground and its slotted patch, antenna is excited by a 50 Ω microstrip line feed with the help of strip 2.5 × 5 mm connected at lower left corner of patch.

5 Results and Discussion

The design and analysis of proposed antenna are performed by IE3D [19] simulator at frequency 2.025 GHz between 1 and 3 GHz frequency. The proposed antenna covers 1259 MHz bandwidth between 1.653 GHz and 2.912 GHz frequency. It displays maximum return loss of −27.63 dB at frequency 2.025 GHz, as shown in Fig. 2. According to return loss plot, antenna provides bandwidth about 56.73% at 2.025 GHz resonant frequency. While antenna design without any slots and notches (shown in Fig. 1a) covers range of frequency 2.209–2.401 GHz (192 MHz) resonating at 2.305 GHz having bandwidth 8.33% with −10.66 dB return loss also illustrated in same Fig. 2. Large bandwidth of proposed antenna geometry is achieved after making different modifications inside rectangular patch like slotting as well as notching. The comparative analysis and size comparison of designed antenna with references [3–11] are shown in Table 3. The size and bandwidth comparison with reference antennas [3–11] is shown in Figs. 3 and 4, respectively.

The proposed antenna has VSWR of 1.102 at frequency 2.025 GHz as shown in Fig. 5. The gain of 4.86 dB and directivity of 4.87 dB have been obtained at frequency 2.025 GHz which are simulated by IE3D software, and its plots are presented in Figs. 6 and 7, respectively. The proposed antenna has high antenna efficiency about 95.77% at frequency 2.025 GHz which is shown in Fig. 8. Smith chart and *Z* parameter of suggested antenna are represented in Fig. 9a, b. The *Z* = 47.94-j4.26Ω (|Z| = 48.13 Ω) is obtained at frequency 2.025 GHz. Simulated radiation pattern (2D, 3D)

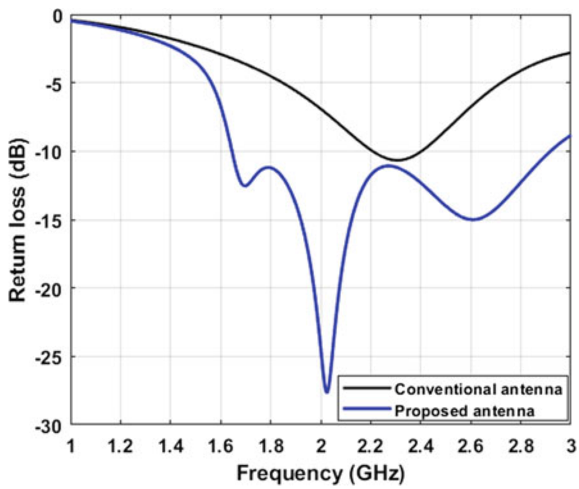


Fig. 2 Bandwidth plot of suggested antenna

Table 3 Comparison of proposed antenna design with references [3–11]

References	Dimensions (mm^2)	Band (GHz)	Resonance Freq.(GHz)	Fractional bandwidth (%)	Uses
[3]	70 × 50 = 3500	1.8–2.6	1.88/2.37	36.7% (800 MHz)	RFID/WLAN
[4]	88 × 62 = 5456	2.382–3.367	3.0	36.5% (985 MHz)	WLAN/WiMAX
[5]	39.04 × 47.64 = 1860	1.639–2.349	1.729/2.223	35.61% (710 MHz)	S-Band
[6]	52.87 × 40 = 2115	2.696–3.061	2.879	12.7% (365 MHz)	Broadband
[7]	120 × 80 = 9600	1.56–2.12	1.84	30.5% (560 MHz)	Broadband
[8]	40.06 × 48.72 = 1951	1.65–2.62	2.41	45.72% (970 MHz)	WLAN
[9]	38.43 × 46.86 = 1800	1.854–3.033	2.477	48.25% (1179 MHz)	WLAN
[10]	88 × 88 = 7744	2.29–2.94	2.45	24.8% (650 MHz)	WLAN/WiMAX
[11]	40 × 48 = 1920	2.233–3.351	2.73	41% (1118 MHz)	WLAN/WiMAX
Proposed	38.42 × 46.86 = 1800	1.653–2.912	2.025	56.73% (1259 MHz)	WLAN/WiMAX

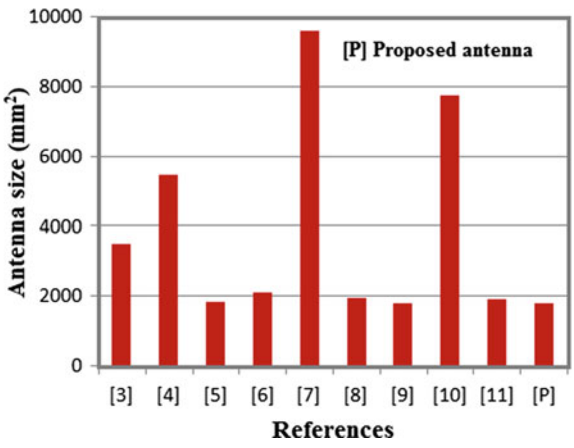


Fig. 3 Antenna size comparisons

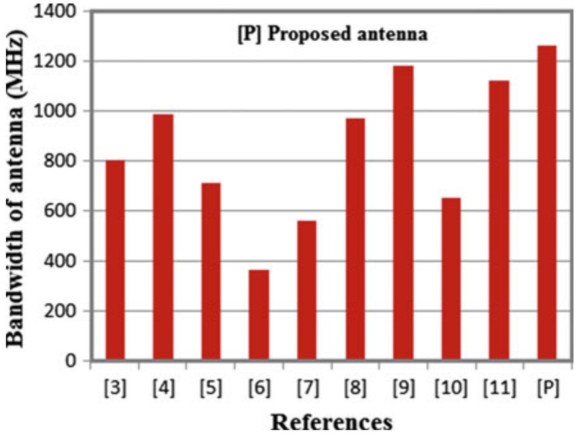


Fig. 4 Bandwidth comparison of antenna

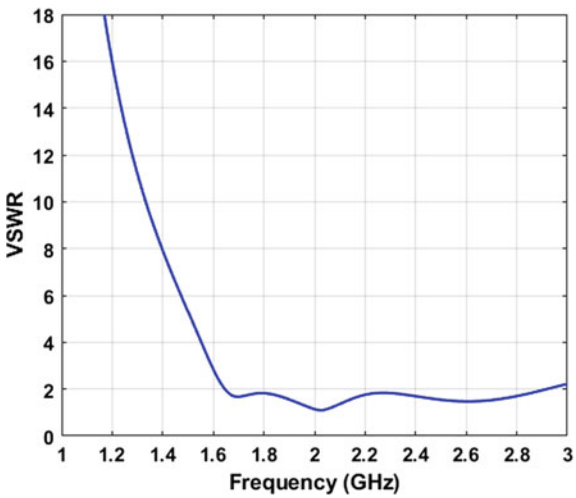


Fig. 5 VSWR of suggested antenna

and current distribution at frequency 2.025 GHz are displayed in Figs. 10, 11, and 12, respectively. 2D radiation pattern is shown at Phi = 0° and Phi = 90° in *E*-plane while at Theta = 0° and Theta = 90° in *H*-plane. 3 dB beamwidth of suggested antenna is 56.54° (72.33°, 128.87°) at frequency 2.025 GHz.

6 Experimental Results

Hardware design (front view and back view) of proposed antenna is displayed in Fig. 13. The measured return loss image measured by vector analyzer is shown in Fig. 14. The measured impedance bandwidth of proposed antenna is achieved

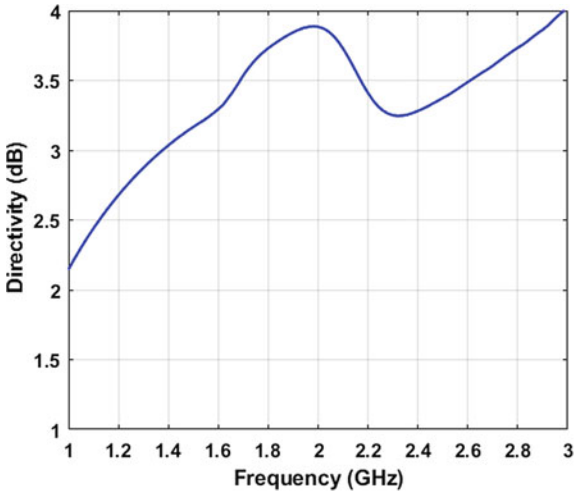


Fig. 6 Directivity of suggested antenna

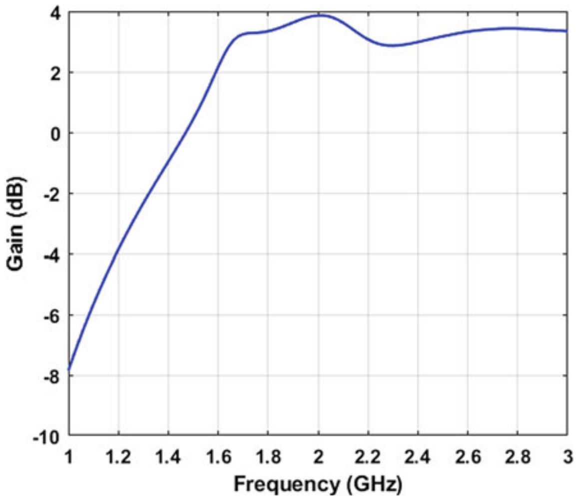


Fig. 7 Gain of suggested antenna

41.38% in the frequency range 1.61–2.45 GHz (840 MHz). Measured antenna design is resonating at frequency 2.04 GHz with −27.28 dB return loss. Bandwidth comparisons of simulated and measured antennas have been displayed in Fig. 15. The small mismatch is occurring in both return losses due to fabrication defect of hardware antenna. Measurement setup image is also shown in Fig. 16.

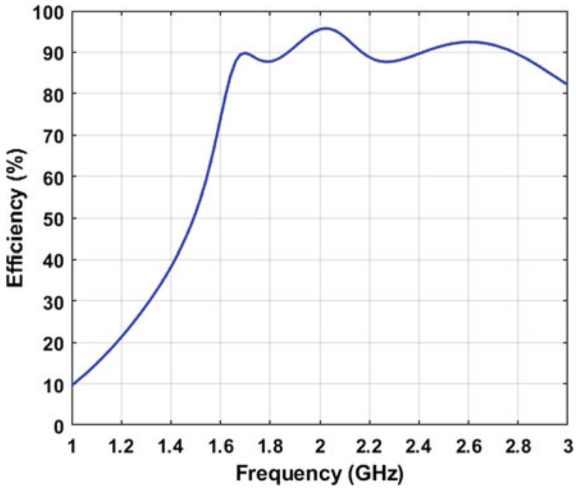


Fig. 8 Antenna efficiency of suggested antenna

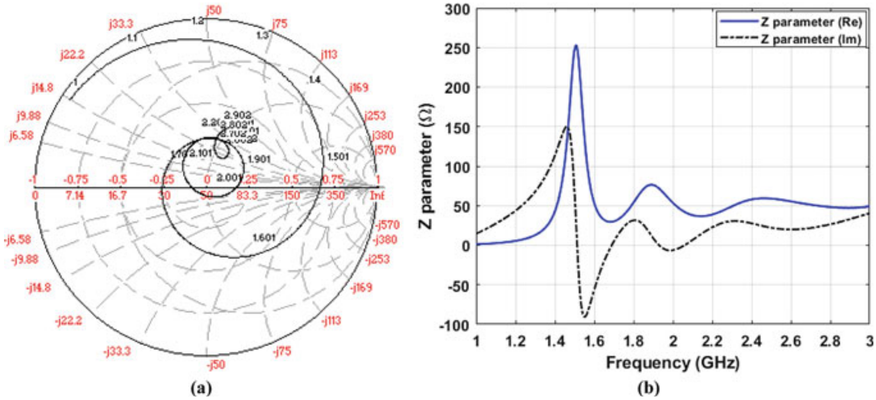


Fig. 9 **a** Smith chart **b** *Z* parameter of suggested antenna

7 Conclusion

Slot and notch loaded rectangular MSA fed by 50 Ω microstrip line fed has been designed and simulated by IE3D on FR-4 (glass epoxy) substrate with wide bandwidth of 56.73% (1259 MHz) resonating at 2.025 GHz between 1.653 and 2.912 GHz. It displays maximum return loss of −27.63 dB and VSWR of 1.102 at frequency 2.025 GHz. The maximum gain of 4.86 dB and antenna efficiency of 95.77% are obtained at resonant frequency. 3 dB beamwidth of suggested antenna is obtained 56.54º (72.33º, 128.87º) at frequency 2.025 GHz. The designed antenna covers frequency band 1.653–2.912 GHz which is suitable for multiple wireless applications.

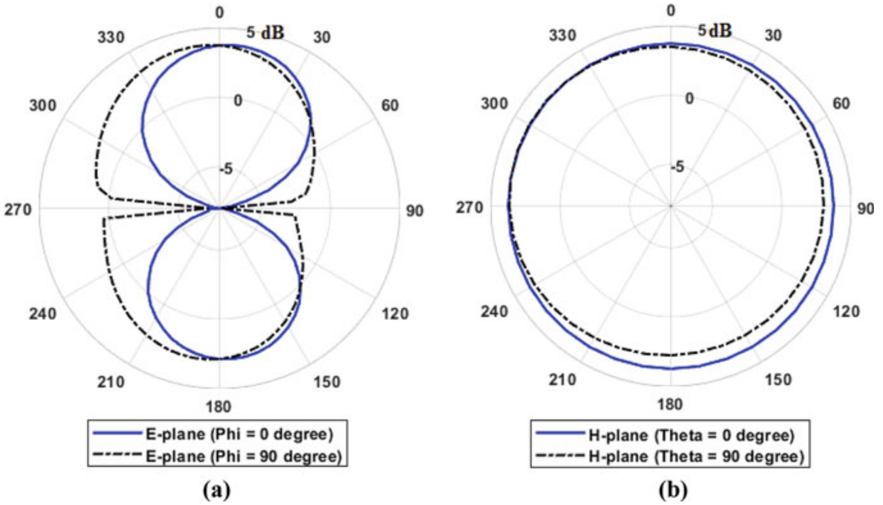
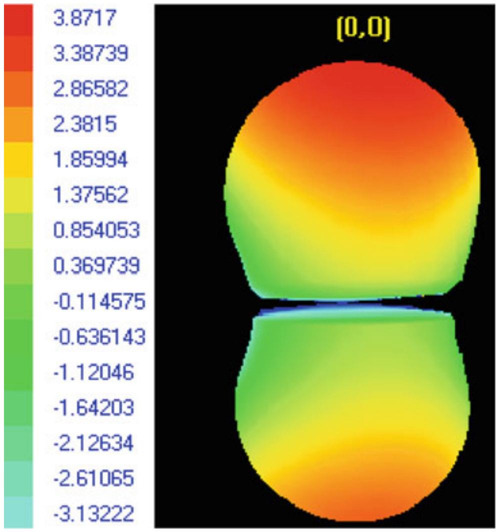


Fig. 10 2D Radiation pattern of suggested antenna at 2.025 GHz for **a** elevation, **b** azimuth

Fig. 11 3D radiation pattern of antenna



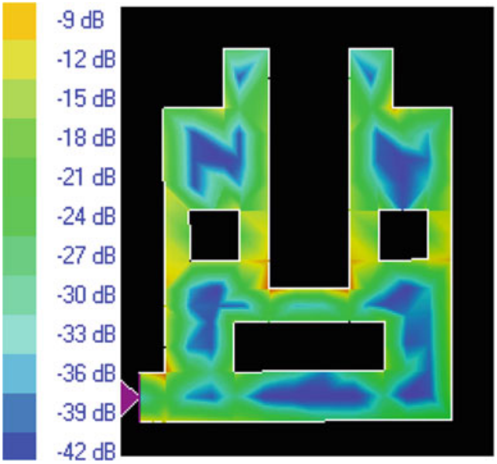


Fig. 12 Current distribution of antenna at 2.025 GHz

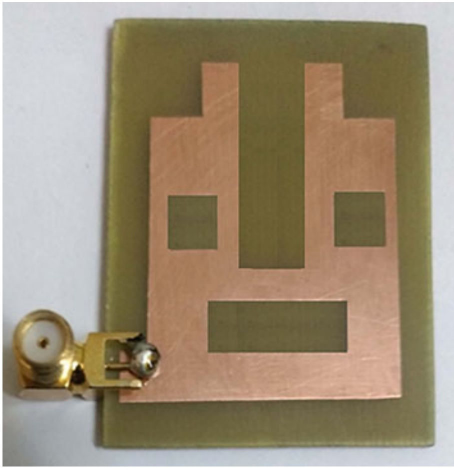


Fig. 13 Hardware design of suggested antenna

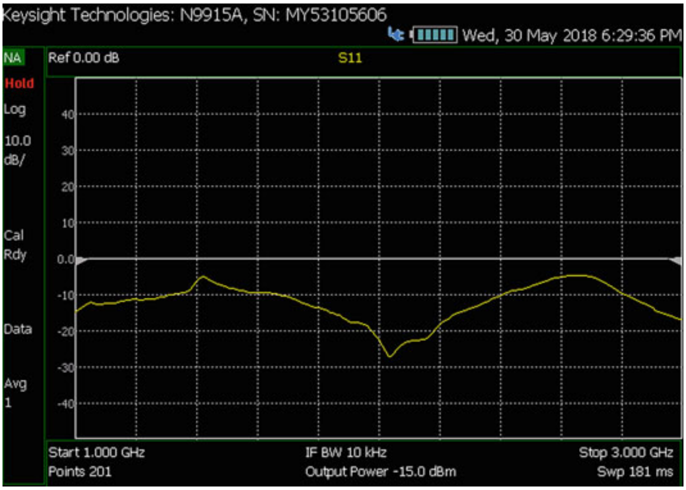


Fig. 14 Measured return loss of suggested antenna

Fig. 15 Return loss of hardware design of antenna

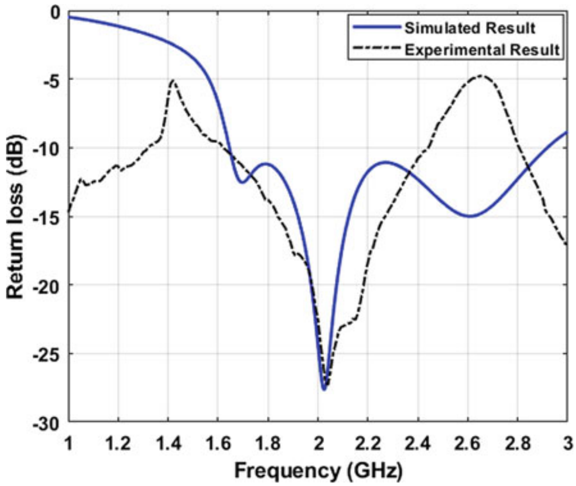


Fig. 16 Setup for return loss measured of suggested antenna

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